Substantiating of Rational Law of Hydrostatic Drive Control Parameters While Accelerating of Wheeled Tractors with Hydrostatic and Mechanical Transmission

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ABSTRACT. The paper explains a process to determine rational laws of change in parameters to control hydraulic units of hydrostatic drive while accelerating wheeled tractors with hydrostatic and mechanical transmissions operating according “input differential” and “output differential”schemes.

The paper substantiates application of rational laws of change in parameters to control hydromachines by determining power distribution within hydraulic and mechanical branches of hydrostatic and mechanical transmissions produced according to “input differential” and “output differential” schemes. Decrease in a zone of power circulation within hydrostatic and mechanical transmissions with output differential has been determined while applying rational laws of changes in control parameters.

Introduction. Constant progress of technologies in the world tractor building makes home tractor manufacturers implement innovative technical solutions to improve technical and economic performance. It results in the necessity to upgrade or modify tractors.

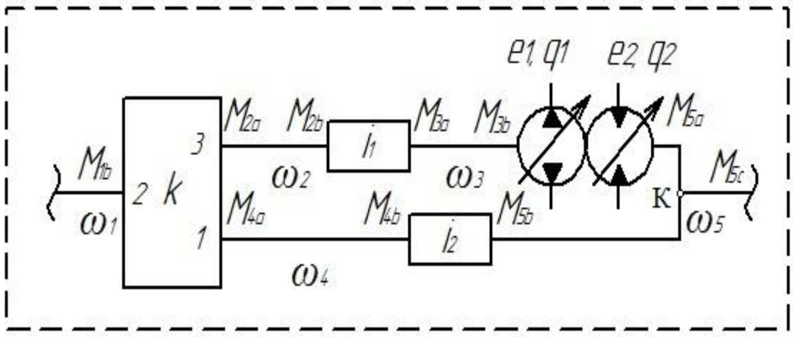
Trying to widen the range of power stream control from a power unit to engines, world tractor manufacturers continue designing stepped mechanical transmissions with the great number of transmission mechanisms; however, they neglect application of less number of shafts, gears, and other mechanical components. Nevertheless, it should be noted that year by year the number of tractors equipped with stepless transmissions, in particular, with hydrostatic and mechanical transmissions (HSMT). That can be explained by advantages of HSMT to compare with stepped transmissions from the viewpoint of smooth motion, increase in ergonomic properties while performing technological operations, automated control etc.

Statement of the problem. As it is known, according to their design HSMTs are divided into “input differential”, “output differential” schemes and those with varied structure. “Input differential” and “output differential” schemes are the most popular as it depends on simple design and less number of mechanical components within transmission.

Consideration of wheeled tractor being integral part of machine and tractor system should involve paying attention to acceleration process while performing technological operation called “plowing” as it means increase in propulsion forces which factors into following significant changes in technical and economic performance: increase in fuel consumption, efficiency decrease as well as effectiveness of machine and tractor system, increase in working pressure difference within hydrostatic drive (HSD), angle velocities and power parameters of HSMT components. Basing upon above it is expedient to determine rational law of change in parameters to control hydromachines while accelerating and substantiate it at the expense of power stream distribution determination within HSMT operating according to “input differential” and “output differential” schemes.

Analysis of the research and publications. Analysis of [1-4] papers has helped develop mathematical model of wheeled tractor accelerating process while performing technological operation called “plowing”. Among other things, paper [1] is applied to determine dynamics of internal combustion engine operation. Motion equation demonstrating changes in crankshaft acceleration has been given to do that. The paper also uses mathematical model of transmission taking into consideration changes in parameters of HSD hydromachines control, volumetric capability of hydromachines, and loss point in hydromachines. It makes it possible to explain an accelerating process of transmissions components in terms of various scheme designs. To explain interaction between wheels and ground in a function of design parameters of tires and physical and mechanical properties of support surface, mathematical model of single traction wheel dynamics while accelerating shown in [1-4] publications is used. They explain interaction of wheels and support surface.

Model of XT3-170/240 line was chosen as base wheeled tractor meant for internal combustion engines with 125 ... 176 kW (170 ... 240 h.p.) motor capacity. [3 – 4] publications have helped select HSMT to be analyzed (Fig. 1) on the criterion of peak efficiency and minimum required motor capacity of internal combustion engine.



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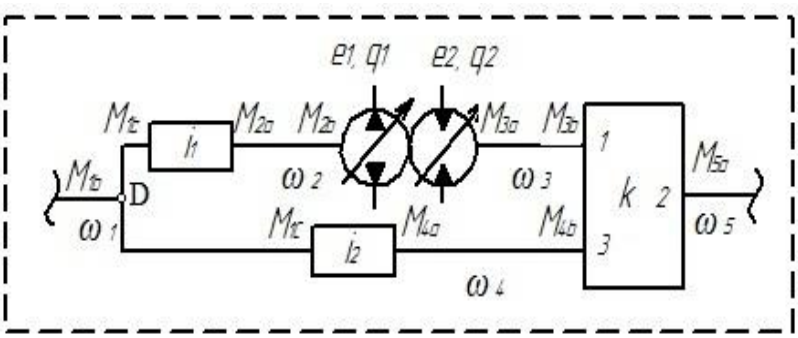

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Fig. 1 Structural patterns of two-flow HSMT: a – “input differential”; b – “output differential”.

According to [5 – 9] papers, distribution of power passing within mechanical branch and hydraulic branch of two-flow HSMT is determined using following equations:

– for HSMT operating with “input differential”:

$$i_{ingid} = \frac{N_{gid}}{N_k} = \frac{M_{2a} \cdot \omega_2}{M_{5c} \cdot \omega_5}; \tag{1}$$

$$i_{inmeh} = \frac{N_{meh}}{N_k} = \frac{M_{4a} \cdot \omega_4}{M_{5c} \cdot \omega_5}; \tag{2}$$

– for HSMT operating with “output differential”

$$i_{exgid} = \frac{N_{gid}}{N_k} = \frac{M_{3a} \cdot \omega_3}{M_{1a} \cdot \omega_1}; \tag{3}$$

$$i_{exmeh} = \frac{N_{meh}}{N_d} = \frac{M_{4a} \cdot \omega_4}{M_{1a} \cdot \omega_1}. \tag{4}$$

Definition of rational law to control parameters of hydromachines while accelerating. Calculations are made within MATLAB system with the help of Simulink subsystem to simulate dynamic processes where generalized mathematical model for wheeled tractor with HSMT accelerating while performing “plowing” operation has been developed.

To form rational laws of changes in parameters to control HSD hydromachines introduce generalized criterion (K_Σ) (with the help of partial criteria it characterizes both efficiency and effectivity of MTS while performing technological operation called “plowing”, and should be maximum)

$$K_\Sigma = \sum_{i=1}^{n} Z_i \cdot K_i + \sum_{j=1}^{m} Z_j \cdot P_j , \tag{5}$$

where Z_i, Z_j are weight coefficients;

K_i – is partial criteria;

P_j – is penalty function which decreases value of generalized criterion when varying parameter is beyond admissible values.

MTS efficiency is estimated on fuel consumption value ($K_1(e_1, e_2)$); to estimate MTS efficiency while performing technological operation called “plowing”, MTS efficiency indices ($K_2(e_1,e_2)$) and temporal value while MTS accelerating($K_3(e_1,e_2)$) are used:

$$K_1(e_1,e_2) = 1 - \frac{Q_P^*(e_1,e_2)}{Q_{P\max}}; \;\; K_2(e_1,e_2) = \frac{\eta^*_{MTA}(e_1,e_2)}{\eta_{\max MTA}(e_1,e_2)}; \;\; K_3(e_1,e_2) = 1 - \frac{t^*(e_1,e_2)}{t_{\max}}, \tag{6}$$

where $Q_P^*(e_1,e_2)$ is current value of fuel consumption;

$Q_{P\max}$ – is maximum of fuel consumption;

$\eta^*_{MTA}(e_1,e_2)$ – is current value of MTS efficiency;

$\eta_{\max MTA}(e_1, e_2)$ – is maximum of MTS efficiency;

$t^*(e_1, e_2)$ – is current value of MTS accelerating period;

$t_{\max}$ – is maximum of MTS accelerating period being determined while applying linear law of change in parameters to control HSD hydromachines.

Changes in $e_1(t)$, $e_2(t)$ parameters either increase or decrease factors working upon a process of MTS accelerating; namely: effective pressure difference within HSD (ΔP), angle velocity on a shaft of hydraulic pump (ω_{e1*}), hydraulic motor (ω_{e2*}) and satellite in planetary gear (ω_S).

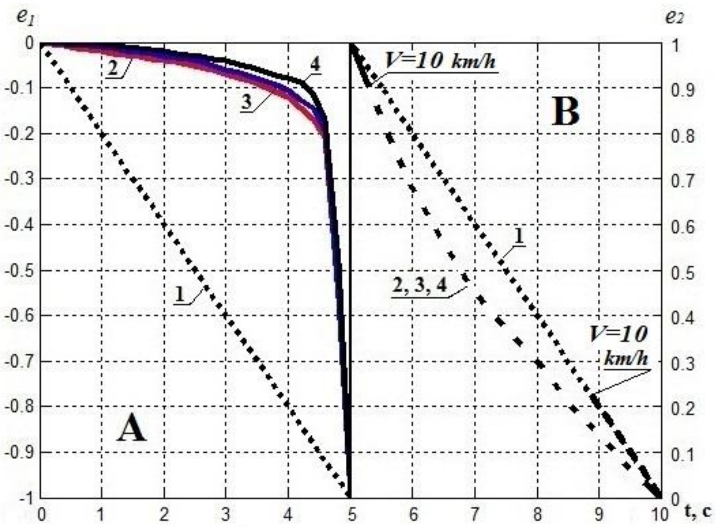
Bound violation factors into the fact that HSMT is out of service; inaccurate results are obtained. Accordingly, penalty functions (P_j) are introduced to show excess of maximum values while optimizing.

Selection of values of weight coefficients for partial criteria involves the fact that sum of weight coefficients Z_i should be equal to 1. Selection of weight coefficients Z_j for penalty functions takes into account that HSMT is out of order when penalty function is beyond the range of change. Thus, identification of rational law of changes in parameters to control HSD hydromachines is to apply one of the methods of optimization theory, i.e. direct search method. The search consists of consequent stages of research around basic point. If it is successful, the next step if the search according to certain sample.

While accelerating MTS in the process of "plowing" operation, generalized criterion characterizing technical and economic performance in the function of parameters controlling HAD hydromachines is

$$K_\Sigma(e_1, e_2) = Z_1 \cdot \left(1 - \frac{Q_P^*(e_1, e_2)}{Q_{P\max}}\right) + Z_2 \cdot \frac{\eta_{MTA}^*(e_1, e_2)}{\eta_{MTA\max}} + Z_3 \cdot \left(1 - \frac{t^*(e_1, e_2)}{t_{\max}}\right) + \\ + Z_{\Delta P} \cdot P_{\Delta P}(|\Delta P|) + Z_{\omega_S} \cdot P_{\omega_S}(|\omega_S|) + Z_{\omega_{e1*}} \cdot P_{\omega_N}(|\omega_{e1*}|) + Z_{\omega_M} \cdot P_{\omega_{e2*}}(|\omega_{e2*}|). \quad (8)$$

Optimization process has formed rational laws of change in parameters to control HSD hydromachines for soil preparation, i.e. crop remains on light, medium-textured, and heavy loams as it is shown in Fig. 2.



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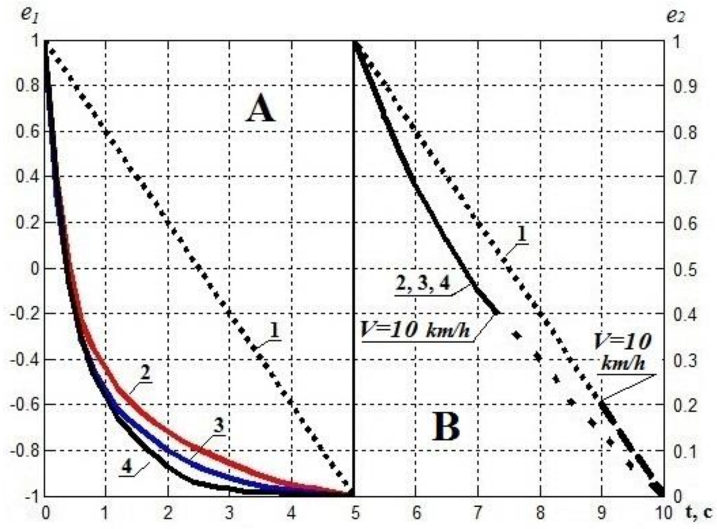
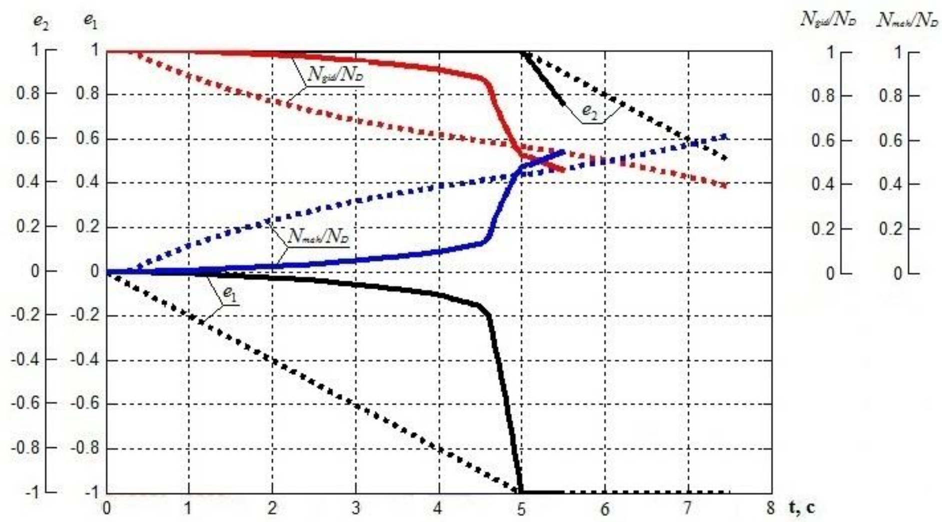


b)

Fig. 2 Changes in parameters to control HSD hydromachines (dependences of controlling parameters e_1, e_2 of HSD hydromachines on t time): a – for "input differential"HSMT; b – for "input differential"HSMT; A is a zone of hydraulic pump control; B is a zone of hydromotor control; 1 are straight functional dependences of change in parameters to control HSD hydromachines; 2 is rational law of change in parameters to control HSD hydromachines for soil preparation in the context of light loams; 3 is rational law of change in parameters to control HSD hydromachines for soil preparation in the context of medium-textured loams; 4 is rational law of change in parameters to control HSD hydromachines for soil preparation in the context of heavy loams.

A process of (1 – 4) equations calculation has identified power distribution for wheeled tractor with HSMT as a part of machine and tractor system while performing "plowing" operation as it is shown in Fig. 3.



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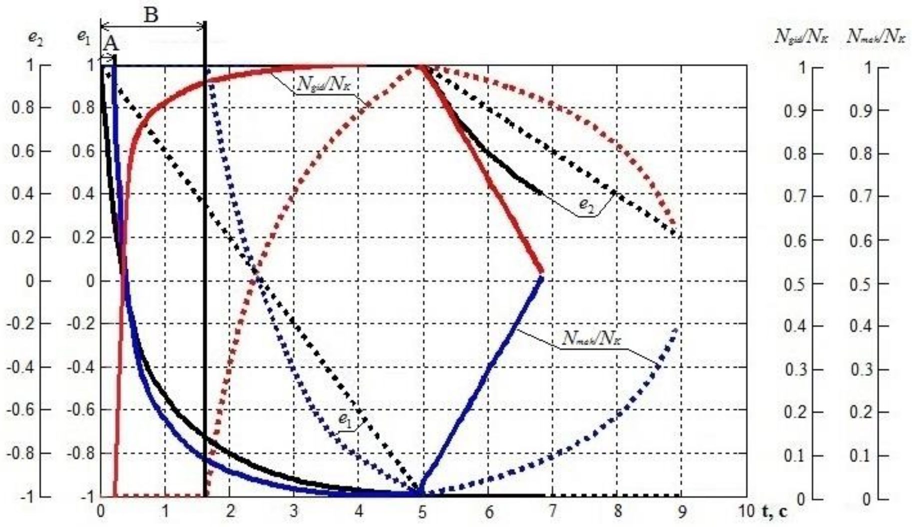

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Fig. 3 Power distribution in HSMT: a – for "input differential"HSMT; b – for "output differential"HSMT; A is circulation zone while applying rational law; B is circulation zone while applying straight functional dependence.

Analysis of Fig. 3 demonstrates that in the initial stage of accelerating when excitation forces are maximal, acceleration process of wheeled tractor with HSMT needs i_{ingid} and i_{ingid} values be peak ones; that is, all forces initiated at accelerating stage and reacting against acceleration where smoothed out by HSD. Moreover, from Fig. 3, b decrease in a zone where power circulation is observed takes place. It is the result of application of rational law of change in parameters to control HSD hydromachines.

Summary. It has been determined that application of rational parameters laws of change in parameters to control HSD hydromachines while accelerating MTS with HSMT according to "output differential" and "input differential" is the utmost: fuel consumption is decreased by 36.2%; MTS efficiency is increased by 29.7%; accelerating period for MTS is decreased by 79.7%; and working pressure difference is decreased by 48.7% to compare with the use of linear functional dependence of change in parameters to control HSD hydromachines.

Interrelation between power distribution within hydraulic and mechanical branches of two-flow HSMT and functional dependences of change in parameters to control HSD hydromachines has been identified.

Decrease in a zone within which power circulation is observed in "input differential" HSMT has been proved owing to application of rational law of change in parameters to control HSD hydromachines.

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